NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

COMPARISON OF THE FUTURE SCOUT VEHICLE USING THE JANUS(A) HIGH RESOLUTION COMBAT MODEL

by

John L. Salvetti

September 1994

Thesis Advisor: Robert R. Read

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
September 1994

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE
COMPARISON OF THE FUTURE SCOUT VEHICLE USING THE JANUS(A) HIGH RESOLUTION COMBAT MODEL(U)

5. FUNDING NUMBERS

6. AUTHOR(S)
Salvetti, John L.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release, distribution is unlimited

12b. DISTRIBUTION CODE
A

13. ABSTRACT (Maximum 200 words)

The purpose of this thesis is to investigate the effects of four different types of scout vehicles when performing a zone reconnaissance as part of a battalion movement-to-contact. The four different types are the current HMMWV (Highly Mobile Multi-Purpose Wheeled Vehicle), and three variants of the future scout vehicle (heavy, moderate, and light). The analysis used the Janus(A) High Resolution Combat Model with a southwest Asia scenario. Operators at Fort Knox, KY and at the Naval Postgraduate School conducted the simulation. Six measures of effectiveness (MOEs) were used in the study. To detect any significant differences between the vehicles each alternative was compared using Scheffé's and Tukey's Methods of Multiple Comparisons The Hierarchical Additive Weighting Method was used to rank the alternatives to determine the best vehicle suited for conducting this specific mission The results from the data collected from both sets of operators indicate that the heavy variant of the FSV is the best vehicle for the zone reconnaissance mission.

14. SUBJECT TERMS
Future Scout Vehicle, Janus(A), Multiple Comparisons, Combat

15. NUMBER OF PAGES
75

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540 01 280-5500

Standard Form 298 (Rev 2-89)

Prescribed by ANSI Std 239-18

Approved for public release; distribution is unlimited.

COMPARISON OF THE FUTURE SCOUT VEHICLE USING THE JANUS(A) HIGH RESOLUTION COMBAT MODEL

John L. Salvetti
Captain, United States Army
B.S., United States Military Academy, 1984

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1994

Author ______________________________
John L. Salvetti

Approved by ______________________________
Robert R. Read, Thesis Advisor

____
Samuel H. Parry, Second Reader

____
Peter Purdue, Chairman
Department of Operations Research

ABSTRACT

The purpose of this thesis is to investigate the effects of four different types of scout vehicles when performing a zone reconnaissance as part of a battalion movement-to-contact. The four different types are the current HMMWV (Highly Mobile Multi-Purpose Wheeled Vehicle), and three variants of the future scout vehicle (heavy, moderate, and light). The analysis used the Janus(A) High Resolution Combat Model with a southwest Asia scenario. Operators at Fort Knox, KY and at the Naval Postgraduate School conducted the simulation. Six measures of effectiveness (MOEs) were used in the study. To detect any significant differences between the vehicles each alternative was compared using Scheffé's and Tukey's Methods of Multiple Comparisons. The Hierarchical Additive Weighting Method was used to rank the alternatives to determine the best vehicle suited for conducting this specific mission. The results from the data collected from both sets of operators indicate that the heavy variant of the FSV is the best vehicle for the zone reconnaissance mission.

TABLE OF CONTENTS

LIST OF TABLES

EXECUTIVE SUMMARY

The scout platoon at the battalion level currently consists of ten HMMWVs (Highly Mobile, Multi-purpose, Wheeled Vehicles). This platoon does not have the capabilities to conduct security and reconnaissance missions into the next century By the year 2010, the Army needs a vehicle that incorporates emerging technology and can successfully conduct all missions of the scout platoon. By using computer simulation one can analyze different vehicle characteristics for the scout platoon to determine the best vehicle suited for the scout platoon missions.

The Janus(A) High Resolution Combat Model was chosen as the computer simulation model because of its ability to provide details down to the individual vehicles The initial step in the analysis was to design a computer scenario that would aid in the process of selecting the best alternative for the scout platoon. Because of the continued tension with Iraq, southwest Asia was chosen as the terrain on which to do the simulation An Iraqi battalion, conducting a meeting engagement, was the enemy encountered In a desert scenario, conducting a zone reconnaissance as part of a battalion movement-to-contact is one of the important missions of the scout platoon, so this was the mission analyzed. Six measures of effectiveness were used to quantify the results obtained from running the computer simulation

The second step in the analysis was to determine if any significant differences existed between the HMMWV platoon and the combined results of the future scout vehicle Scheffé's Method of Multiple Comparisons was used to compare the average of the results from the three variants of the future scout vehicle against the results collected from the HMMWV platoon This analysis demonstrated that significant differences did exist between the platoons

Once significant differences were detected with the initial comparison, the third step in the analysis was to conduct comparisons among the four distinct platoons Tukey's Method of Multiple Comparisons was used to determine if significant differences existed between the platoons. This method revealed the differences between the platoons but could not quantify the results to lead to the selection of the best alternative for configuring the scout platoon. The final step in the analysis was to use the results from Tukey's method to quantify the results. The Hierarchical Additive Weighting Method was the tool used to accomplish this quantification. The existence or nonexistence of significant differences were used as inputs into the weighting method in order to rank the alternatives. When analyzed using these specific parameters, the data collected from both sets of operators indicated that the heavy variant of the future scout vehicle is the best configuration of the scout platoon.

I. INTRODUCTION

The Commander must be able to see the battlefield. The first step in winning is seeing the battlefield. If the commander can't see the battlefield - before and during the battle - the day, the battle, maybe even the war is lost. [Ref. 1]

A. OVERVIEW

To win on the battlefield, the heavy armor battalion commander must synchronize all of his combat multipliers to focus combat power at the decisive time and place. Two important considerations for commanders are that of reconnaissance and security. Accurate reconnaissance and security operations provide the commander the necessary information to mass his force and exploit the enemy's weaknesses. Reconnaissance success is a necessary pre-condition for mission success. The scout platoon is organized, equipped, and trained to conduct reconnaissance and security for the battalion-sized unit. The scout platoon serves as the commander's eyes and ears on the battlefield. It provides current battlefield information to help the commander plan and conduct tactical operations. As technology changes, the scout platoon must also maintain its capability and effectiveness, thus giving the commander the most reliable information on which to make his decisions. The primary missions of the scout platoon are:

- Reconnaissance.
- Screening in support of its parent unit. [Ref. 2]

Reconnaissance failures, throughout history, have contributed directly to many military failures. The battles of Gettysburg, Midway, Remagen, and Sontay, Vietnam are all examples of reconnaissance failures. RAND data collected at the National Training Center indicate that 90% of all successful missions are characterized by successful reconnaissance, while in only 15% of all examined missions was successful reconnaissance not accompanied by mission success. [Ref. 3] Inherent in the continued success of reconnaissance is a vehicle that will be able to perform into the 21st century. A reasonable approach is to study different configurations of the scout vehicle and to determine which combination of characteristics is best for accomplishing the scout platoon missions. The effects of these different characteristics may be studied when implemented into the Janus(A) combat model used for analysis. After the simulation is run, pairwise comparisons will be done on each scout platoon alternative to determine the superior type of vehicle for accomplishing the mission.

B. BACKGROUND

The Army has recognized the need for a new scout vehicle. The following conclusions were drawn from the Army Modernization Plan:

> Current scout vehicles cannot adequately collect threat information, locate targets, synchronize fire beyond line-of-sight, perform security missions, identify targets during periods of limited/obscured vision and identify air/ground targets beyond visual range ... and integrate information for battlefield decision-making. [Ref. 4]

The Army has recognized these deficiencies and in the near and mid term has devised a strategy for improving current vehicles. In the far term (FY01 and beyond) the Army wants a different vehicle that employs maturing technologies. This vehicle needs to be a highly mobile platform incorporating stealth technology, advanced vehicle electronics and communications, and integrated defensive measures for high survivability. The Future Scout Vehicle (FSV) must operate throughout the battlefield and use an integrated day/night, all-weather surveillance and target acquisition system to locate high priority targets. The FSV also has a direct fire weapon capable of defeating light armor, and performs the full range of ground reconnaissance and security missions as well as economy of force operations. [Ref. 4: p. A-42]

C. NATURE AND ROLE OF JANUS(A)

JANUS(A) is a high resolution model used for combat analysis. The model is an interactive, two-sided, closed, stochastic ground combat simulation. Interactive refers to the interplay between players who decide what to do in crucial situations during simulated combat and the systems which model that combat. Two-sided refer to the two opposing forces directed simultaneously by two sets of players. Closed means that the disposition of opposing forces is largely unknown to the players in control of the other force. Stochastic refers to the way the system determines the results of actions such as direct fire engagements; according to the laws of probability. Ground combat means that the principal focus is on ground maneuver and artillery units. [Ref. 5]

The JANUS data base describes systems extensively and in great detail. Individual fighting systems have distinct properties: dimensions, weight, carrying capacity, speed, weapons, and weapons capabilities such as range, type of ordnance, and other processes that influence combat outcomes.

In JANUS, the simulation entities are individual combat vehicles or weapon systems giving the analyst the ability to observe and modify the parameters of individual combat processes. These modifications will generate observations to use in the analysis.

The simulation used digitized terrain developed by the Defense Mapping Agency, displaying it in a form familiar to the military, using contour lines, roads, rivers, vegetation, and urban areas. Digitized terrain features realistically affect visibility and movement.

A feature called AUTOJAN permits playback or replay of a previously executed Janus scenario run. During the original scenario run, all manual actions made by the users are saved. When the scenario is replayed in AUTOJAN mode, the user can specify that one or more of the workstations assigned to the original scenario run retrieve their manual actions from the recording file rather than new user input.

II. MODEL METHODOLOGY

If I am able to determine the enemy's disposition while I at the same time conceal my own, then I can concentrate and he must divide ... and I can use my entire strength to attack a fraction of his. [Ref. 6]

A. SCOUT PLATOON MISSION

The scout platoon, as part of a battalion-sized unit, must perform numerous primary and secondary missions, to include: route reconnaissance, zone reconnaissance, area reconnaissance, screen, guard, and cover. The zone reconnaissance is one mission that the platoon must perform extensively in the desert scenario. Scouts conduct zone reconnaissance missions for their parent unit to provide early warning of enemy approach and to provide real-time information, reaction time, and maneuver space for the main body. A commander calls on scouts to conduct the zone reconnaissance for him when he needs advance warning of when and where the enemy is attacking. Operating over an extended area, the platoon fights only for self-protection and remains within its capabilities. It denies enemy reconnaissance units close-in observation of the main body. In this model, the scout platoon conducts a zone reconnaissance for a balanced task force conducting a movement-to-contact. As currently configured, the vehicles in the scout platoon cannot effectively conduct a zone reconnaissance. The problem is to determine what type of vehicle is best suited for accomplishing this specific mission within the guidelines of a battalion movement-to-contact.

B. JANUS(A) TACTICAL SCENARIO

1. U. S. Forces

a. Mission

The mission of the U.S. force is to conduct a movement-to-contact against an Iraqi force in southwest Asia. A movement-to-contact is an operation conducted to gain or reestablish contact with the enemy. Its purpose is the early development of the situation to provide an advantage prior to decisive engagement. A reconnaissance force precedes the main body to give it the necessary time to develop the situation. It is characterized by decentralized control and rapid commitment of forces from the march.

b. Disposition of forces

The scout platoon is conducting the zone reconnaissance mission for a balanced task force. The task force consists of two armor companies of 14 tanks (M1A2) each and two mechanized infantry companies of 14 infantry fighting vehicles (M2A2) each. The indirect fire support consists of the organic 120mm mortar platoon, a 155mm self-propelled artillery battalion, and one section of MLRS (Multiple, Launched, Rocket System).

2. Iraqi forces

a. Mission

The Iraqi force will be conducting a meeting engagement. The general principals followed by Iraqi forces in meeting engagements include:

- Avoiding enemy strong points
- Rapid maneuver
- Movement to the enemy rear [Ref. 7]

b. Disposition of forces

The forces that the scout platoon and the task force will be encountering are in the advance party of an advance guard of a division column. The main combat vehicles in this size unit are 26 tanks (T72), 13 infantry fighting vehicles (BMP-2), and a 152mm artillery battalion in direct support. Figure 1, on the next page, shows the disposition of forces at the beginning of the scenario.

C. SCOUT PLATOON CONFIGURATIONS

Four different platoons will be studied. These platoons will be a base case, a future scout vehicle (light) version, a future scout vehicle (moderate) version, and a future

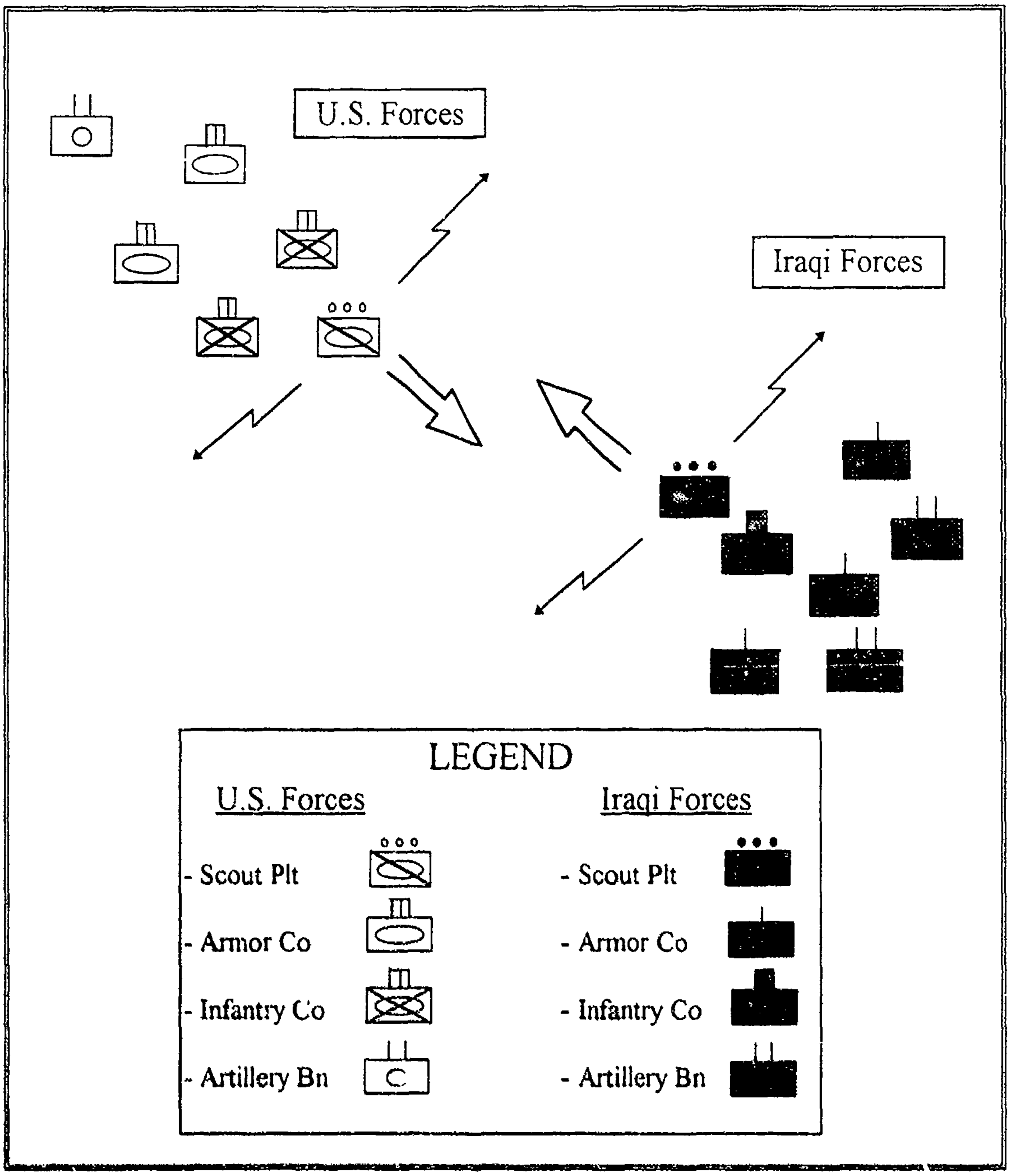

Figure 1. Movement-to-contact

scout vehicle (heavy) version. For the analysis, different characteristics of the vehicles will varied in Janus(A) according to the projected capabilities. The seven major attributes are artillery ballistic protection, direct fire ballistic protection, countermeasures, signature factor, maximum land speed, sensors, and armament. Some characteristics of the FSV do not currently exist in Janus(A). Considering the projected capabilities for the FSV, a similar parameter from a vehicle that currently exists in the database will be used. For example, the heavy variant is projected to have a missile launcher system that exceeds the capability of the current system. To model this improved missile system, the attributes of a Hellfire missile system were used. The countermeasures for the FSV variants degrade the missile probability of hit by 25%. This figure is assumed true for this study based on conversations with the Analysis and Force Development Divisions at Fort Knox, KY. The attributes used for each vehicle are explained in detail in the following paragraphs and summarized in Table 1 on page 10. [Ref. 8]

1. Base Case

The base case scout platoon consists of the current ten Highly Mobile Multi-Purpose Wheeled Vehicles (HMMWV). The HMMWV is up-armored to account for changes to the outside of the vehicle currently being developed. For artillery ballistic protection, the platoon vehicles have the characteristics of the average between an armored personnel carrier and a light wheeled vehicle. For direct fire ballistic protection, the characteristics are that of an up-armored HMMWV. The HMMWV does not have any current countermeasures that would affect the enemy's ability to engage it. It has a signature factor of 1.8 meters. The signature is the term used to describe the size of the vehicle that is presented to the enemy in the simulation. The signature takes into account the height, width, and length of the vehicle. The larger the signature, the easier it is for the enemy to detect and engage the vehicle. The maximum land speed for the HMMWV is 105 km/hr. The sensors used for identifying and classifying the enemy are the naked eye, 7 X 50 binoculars, and a sight comparable to the M1A1 thermal sight. Five HMMWVs of the platoon carry the 7.62mm machine-gun and a .50 caliber machine-gun, while the other five carry the 7.62mm machine-gun and the MK-19 grenade launcher.

2. Future Scout Vehicle (light)

The FSV (light) platoon consists of ten vehicles. Its primary mission is to be able to detect the enemy at extended ranges. This platoon does not have the capability to destroy anything greater than enemy wheeled vehicles. For artillery ballistic protection, the FSV (light) has the average value between an armored personnel carrier and a light wheeled vehicle. The direct fire ballistic protection is the same as that of the up-armored HMMWV. Because of the projected stealth capability of the future scout vehicle, it has by use of countermeasures, the ability to degrade the probability that it will be engaged by an enemy missile system by 25%. Its signature factor is 0.5 meters. The maximum speed for the FSV (light) is 110 km/hr. The sensors on the vehicle are 8 X 50 binoculars, a mast mounted thermal sight, and a Target Acquisition Designation System (TADS-TV). The TADS-TV consists of a Light Helicopter sight (LHX-TV) and an Air Defense Acquisition Tracking System (ADATS- TV). For its armament it only carries a 7.62mm machine-gun.

3. Future Scout Vehicle (moderate)

The FSV (moderate) platoon consists of ten vehicles. It is designed to detect the enemy at extended ranges and has the capability to destroy some light armored enemy vehicles For its artillery ballistic protection, it has the average value of the characteristics between an armored personnel carrier and a medium tracked vehicle. For its direct fire ballistic protection it has the characteristics equal to a M113 armored personnel carrier. The countermeasures are the same as the light version. Its signature factor is 0.8 meters. The maximum land speed for the FSV (moderate) is 95 km/hr. The sensors it carries are 8 X 50 binoculars, a mast mounted thermal sight, and a TADS-TV. For its armament it has a 25mm chain gun and can dismount a soldier to fire the Javelin.

4. Future Scout Vehicle (heavy)

The FSV (heavy) platoon consists of ten vehicles. It is designed to detect the enemy at extended ranges and to defeat enemy armored vehicles. For its artillery ballistic protection, it has the average value of the characteristics between an armored personnel carrier and a medium tracked vehicle. For the direct fire ballistic protection is has the same characteristics as that of a M3 Bradley Fighting Vehicle. The countermeasures are the same as the light and moderate versions. Its signature factor is 1.2 meters. The maximum land speed for the FSV (heavy) is 89 km/hr. Its sensors are 8 X 50 binoculars, a mast mounted thermal sight, and a TADS-TV. Its armament consists of a 25mm chain gun, Javelin, and the Hellfire missile. The different attributes for each platoon that are used in the Janus(A) database are summarized in Table 1.

		FSV		
	HMMWV	Light	Moderate	Heavy
Artillery Ballistic Protection	APC/Light wheeled vehicle	APC/Light wheeled vehicle	APC/Medium tracked vehicle	APC/Medium tracked vehicle
Direct Fire Ballistic Protection	HMMWV Up-armored	HMMWV Up-armored	M113	M3A3
Countermeasures	none	degrade missiles probability of hit by 25%		
Signature Reduction Factor	1.8	0.5	0.8	1.2
Armament	.50 cal 7.62mm MK19 GL	7.62mm	25mm Javelin	25mm Hellfire Javelin
Sensors	Eyes Binos (7x) M1 Thermal	TADS-TV Thermal Sight (Mast mtd) Binos (8x)	TADS-TV Thermal Sight (Mast mtd) Binos (8x)	TADS-TV Thermal Sight (Mast mtd) Binos (8x)
Land Speed (kph)	105	110	95	89

Table 1. Scout Platoon Attributes

III. ANALYSIS METHODOLOGY

A. RUN MATRIX

The HMMWV equipped platoon and the FSV variants will execute the movement-to-contact mission one time. Five more runs will be executed using the AUTOJAN mode. AUTOJAN uses the actions of the first man-in-the-loop run and produces similar actions and reactions based on a random seed. The six runs will be accomplished by operators at Fort Knox, Kentucky and at the Naval Postgraduate School, Monterey. There are a total of 6 repetitions per cell. Each run produces a direct fire report, detection report, and coroner's report for analysis. The results from the summarized reports are included in Appendix A.

B. OVERVIEW

Initially, each location will be analyzed separately to determine the best alternative for the scout platoon configuration. First, Scheffé's multiple comparison test will be used first to determine the trends between the FSV variants, taken as a whole group, versus the HMMWV. Second, Tukey's multiple comparison test will be used to determine if significant differences exist between all vehicle alternatives for each measure of effectiveness. The significant differences will then be used for input into the hierarchical additive weighting method to establish the best vehicle variant taking all measures of effectiveness into consideration.

C. ESSENTIAL ELEMENTS OF ANALYSIS

This study will concentrate on four essential elements of analysis to detect any discernible differences between the different variants of the scout vehicles. The elements will be concerned with the scout platoon's ability to accomplish the basic collective tasks necessary to perform a successful zone reconnaissance as part of a battalion

1. Essential Elements of Analysis 1

The first essential element of analysis is to determine how well is the platoon able to detect and report all enemy forces in its area of interest. An integral component of any scout mission is its ability to perform reconnaissance. The scout platoon must report quickly and accurately to the battalion commander so he can make the proper battlefield decisions. The two measures of effectiveness used to quantify the platoons will be:

- The average range of detections of Iraqi forces by U.S. scout platoon personnel in the first forty minutes of the battle.
- The total number of detections of Iraqi forces by the U.S. scout platoon during the first forty minutes of the battle.

The time element of forty minutes was used because that is when, during the simulation, the main body of the Iraqi force had closed to within engagement distance of the U.S. force. The scouts are able to have the greatest effect on the outcome of the battle during the initial lead-in to the main battle.

2. Essential Elements of Analysis 2

The second element of analysis is to determine how well is the platoon able to survive while performing its mission. The greater the number of vehicles that remain functional on the battlefield, the greater the capacity for the platoon to conduct all of its missions. The one measure of effectiveness used for the analysis is:

- The number of U.S. scout platoon vehicles that survived at the completion of the battle.

The stopping criterion for the completion of the battle was when the U.S. forces had captured their objective. At this time, a numerical count was taken of the remaining scout platoon vehicles.

3. Essential Elements of Analysis 3

The third essential element of analysis is to determine how well is the scout platoon able to perform surveillance without being detected. The scout platoon must be able to continually perform surveillance on the enemy without compromising its position Once its position is jeopardized, the commander does not know if the scout platoon is receiving accurate intelligence information or knowledge that the enemy wants him to receive The two measures of effectiveness used to quantify the platoons will be:

- The average range that the U.S. scout platoon vehicles were detected by Iraqi forces.
- The time difference of the first U.S. detection and the first Iraqi detection.

These measures of effectiveness will demonstrate which platoons were able to give the commander the maximum time to process his available information before having to give an execution order to his maneuver forces.

4. Essential Elements of Analysis 4

The fourth essential element of analysis is to determine how well is the unit able to repel and/or destroy enemy forces The one measure of effectiveness used for the analysis is.

- The number of Iraqi kills by U.S. scouts.

When the simulation has reached the stopping criterion, a numerical count is taken on the number of Iraqis that were killed by any weapon system on the scout platoon vehicles This MOE was used because some commanders believe it is important for the scouts to be able to kill the enemy within its capability

G. THE ANALYSIS OF VARIANCE (ANOVA) MODEL

The basic elements of the ANOVA model for a single-factor study are quite simple Corresponding to each factor level, there is a probability distribution of responses The ANOVA model assumes that

- Each of the probability distributions is normal
- Each probability distribution has the same variance
- The observations for each factor level are random observations from the corresponding probability distribution and are independent of the observations for any other factor level [Ref 9].

In this study, the third assumption is supported by the nature of the simulation. Verifications are made on the first two. To determine if each of the probability distributions is normal, a normal probability plot of the residuals was constructed on some of the measures of effectiveness. This cursory analysis indicated a normal distribution with some departure from normality, but as stated by Montgomery, "in general, moderate departures from normality are of little concern in the fixed effects analysis of variance. Since the F test is only slightly affected, the analysis of variance (and related procedures such as multiple comparisons) is robust to the normality assumption." [Ref. 10]

A separate test will be conducted to determine if each probability distribution has a common variance. The Hartley test will be employed to test for common variances. The test will be illustrated on a few of the measures of effectiveness, but performed on all the remaining measures.

1. Hartley Test

The Hartley test is based solely on the largest sample variance, denoted by max (s_i^2), and the smallest variance, denoted by min (s_i^2). The test statistic is:

$$H = \frac{\max(s_i^2)}{\min(s_i^2)} \tag{1}$$

The appropriate decision rule for controlling the risk of making a Type I error at α is:

If $H \leq H(1 - \alpha; r, df)$, conclude H_0 that variances are equal

If $H > H(1 - \alpha; r, df)$, conclude H_a that variances are unequal where $H(1 - \alpha; r, df)$ is the $(1 - \alpha)100$ percentile of the distribution of H when H_0 holds, for r populations and df degrees of freedom for each variance [Ref. 9: p. 619]. In this case $H(.95; 4, 5) = 13.7$. This value will be computed for two measures of effectiveness to illustrate that all measures of effectiveness satisfy the same variance assumption.

1. *Measure of Effectiveness 1 for Fort Knox Simulation*

$$H = \frac{0.2913}{0.0253} = 11.5$$

since $11.5 \leq 13.7$, H_0 is concluded that all variances may be treated as equal.

2. *Measure of Effectiveness 3 for NPS Simulation*

$$H = \frac{1.3667}{0.6667} = 2.05$$

since $2.05 \leq 13.7$, H_0 is concluded that all variances are assumed to be equal. A special consideration in using this test concerns the measure of effectiveness for the number of Iraqi kills for the scout platoon. In this case the variances for the HMMWV and FSV (light) platoons were zero because of the deterministic nature of the number of kills for these platoons. These platoons did not register a kill in twelve replications, and because of the nature of the scenario and their armament will not register any kills in any future replications. Because of this situation, the test was only administered to the variances for the moderate and heavy variants of the FSV The single factor ANOVAs for all the measures of effectiveness are included in Appendix B.

H. METHODS OF MULTIPLE COMPARISONS

1. Scheffé's method of multiple comparisons

Scheffé's method of multiple comparisons is applicable for analysis of variance models. The Scheffé Method applies for analysis of variance models when the family of interest is the set of estimates of all possible contrasts among the factor level means A contrast is a comparison involving two or more factor level means and includes the case of a pairwise difference between two factor level means. Here the method will be used to contrast the FSV family of vehicles with the HMMWV to determine if the FSV variants outperform the HMMWV in all cases. A contrast will be denoted by L, and is defined as a linear combination of the factor level means μ_i:

$$L = \sum c_i \mu_i \quad \text{where} \quad \sum c_i = 0 \tag{2}$$

The Scheffé method family confidence coefficient is exactly 1 - α whether the factor level sample sizes are equal or unequal.. An unbiased estimator of L is:

$$\hat{L} = \sum_{i=1}^{4} c_i \bar{Y}_i \tag{3}$$

for which the estimated variance is:

$$S_{\hat{L}} = \sqrt{MS_E \left[\frac{(c_1)^2 + (c_2)^2 + (c_3)^2 + (c_4)^2}{n} \right]} \tag{4}$$

and the probability is 1 - α that all confidence limits of the type:

$$\hat{L} = L \pm K[S_{\hat{L}}] \tag{5}$$

are correct simultaneously, where K is given by:

$$K = \sqrt{(r-1)F[1-\alpha; r-1, n_t - r]} \tag{6}$$

where r is the number of different types of vehicles, n_t is the total number of observations, and L is the difference of the means [Ref 10: p. 72]. Thus if we were to calculate the confidence intervals for all conceivable contrasts then in (1- α)100 percent of repetitions of the experiment, the entire set of confidence intervals in the family would be correct. If the confidence interval contains zero then the compared vehicles are not significantly different. In the case of general contrasts the Scheffé method tends to give narrower confidence limits and is therefore the preferred method. When only pairwise comparisons are to be made, the Tukey multiple comparison procedure gives narrower confidence limits and is therefore the preferred method.

2. Tukey's method of multiple comparisons

The Tukey method of multiple comparisons considered here applies when the family of interest is the set of all pairwise comparison of factor level means. The Tukey method utilizes the *studentized range distribution.* The procedure requires the use of q_α (a, f) to determine the critical value for all pairwise comparisons, regardless of how many means are in the group. Thus, Tukey's test declares two means significantly different if the absolute vale of their sample differences exceeds

$$T_\alpha = q_\alpha(a,f)S_{\bar{Y}_i} \tag{7}$$

where $q_\alpha(a, f)$ is the studentized range statistic, and $S_{\bar{Y}_i}$ is defined as

$$S_{\bar{Y}_i} = \sqrt{\frac{MS_E}{n}} \tag{8}$$

where MS_E is the mean squared error of the residual and n is the number of replications [Ref 10: p. 78]. If the difference of the means of the compared vehicles is less than the T_α value than the two vehicles are not considered significantly different. In this analysis, Tukey's method will be used to compare each vehicle with every other vehicle. The results from Tukey's test will then be used in the hierarchical additive weighting method (HAWM) to determine the ranking of the scout platoon vehicle alternatives.

IV. RESULTS

A. SCHEFFÉ'S METHOD OF MULTIPLE COMPARISONS

1. Fort Knox simulation runs

For the average range of U.S. detections the analysis yielded

$$L = \frac{5.73 + 6.16 + 6.29}{3} - 5.45 = 0.61$$

$$S_{\hat{L}} = \sqrt{0.1359\left[\frac{\left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + (-1)^2}{6}\right]} = 0.1738$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\vec{B} = 0.61 \pm (3.0496)(0.1738) = 0.61 \pm 0.53$$

Using an $\alpha = 0.05$, the confidence interval does not contain zero, so there is not a significant difference between the FSV family of vehicles and the HMMWV for this measure. Appendix C contains the computations of Scheffé's method for all the measures of effectiveness. The results for the MOEs are summarized in Table 2 below.

	Confidence Interval	Significant
Average range of U.S. detections	0.61 ± 0.53	Yes
Total # detected by U.S. scouts	26.23 ± 20.19	Yes
U.S. scout survivors	5.61 ± 2.39	Yes
Avg range of det. of U.S. scouts	0.41 ± 0.69	No
Time difference of first detections	3.60 ± 4.46	No
# of kills by U.S. scouts	6.33 ± 1.80	Yes

Table 2. Scheffé's Method for Fort Knox

The FSV variants outperformed the HMMWV in four of the measures of effectiveness If all the MOEs are given the same degree of consideration for determining the best alternatives between the two choices, then the FSV variants are clearly the better type of vehicle. There were no discernible differences in the measures of the average range of detection by the Iraqi's of the U.S. scouts, or the time difference of the first detections. One would expect the FSV variants to be superior in the number of Iraqi kills because of the high degree of armament that exists on the heavy variant. The results do show that the FSV variants do detect the enemy, on the average, from a farther distance and they can monitor the enemy's actions more closely, as seen by the total number of detections.

2. Naval Postgraduate School simulation runs

The results for the simulation runs made by the Naval Postgraduate School operators are summarized below in Table 3.

	Confidence Interval	Significant
Average range of U.S. detections	0.42 ± 0.53	No
Total # detected by U.S. scouts	37.17 ± 11.79	Yes
U.S. scout survivors	3.50 ± 1.42	Yes
Avg range of det. of U.S. scouts	0.11 ± 0.53	No
Time difference of first detections	5.79 ± 3.71	Yes
# of kills by U.S. scouts	10.61 ± 3.79	Yes

Table 3. Scheffé's Method for NPS

In these simulation runs the FSV variants outperformed the HMMWV in four of the measures of effectiveness. In this case the four measures were not the same as seen from the Fort Knox operators. There were no discernible differences in the average range of detection by the U.S. scouts or in the average range of detection by the Iraqis of the U.S. scouts. The latter measure of effectiveness was the same for both sets of operators.

The data collected from the NPS operators indicated significance in the time difference of first detections. This contrast could be attributed to the difference in the execution of U.S. doctrine between themselves and the Fort Knox operators. The FSV variants did, as expected, outperform the HMMWV in the number of Iraqi kills. When all six MOEs are analyzed together, the FSV variant is the better alternative for conducting a zone reconnaissance as part of a battalion movement-to-contact. Since the FSV variants did outperform the HMMWV, the next step in the analysis is to rank the alternatives.

B. TUKEY'S METHOD OF MULTIPLE COMPARISONS

1. Fort Knox simulation runs

The following results were obtained for the measure of effectiveness of the average range of detections:

$$q_{.05}(4,20) = 3.96$$

$$S_{\bar{Y}_i} = \sqrt{\frac{0.1359}{6}} = 0.1505$$

$$T_{.05} = (3.96)(0.1505) = 0.5960$$

Vehicle	HMMWV	Light	Heavy	Moderate
Avg. range of detection	5.45	5.73	6.16	6.29

where the lines serve as a schematic that represents the difference of the means that are less than the $T_{.05}$ value. These lines represent the results that are not significantly different from each other. For example, in the first MOE, the lines are under the pairs HMMWV-light, light - heavy, light moderate, and heavy - moderate, indicating no significant difference between these pairs of vehicles. Appendix D contains the comparisons for all the measures of effectiveness. Table 4, on the next page, summarizes the relationship of the vehicle configurations for all the MOEs. If Tukey's method did not find a significant difference then NO was entered into the table while a YES was entered for a significant difference.

	MOE 1 - Avg range of U.S. detections			
	HMMWV	Light	Moderate	Heavy
HMMWV	---	NO	YES	YES
Light	---	---	NO	NO
Moderate	---	---	---	NO
	MOE 2 - Total # detected by U.S. scouts			
HMMWV	---	YES	YES	YES
Light	---	---	NO	NO
Moderate	---	---	---	NO
	MOE 3 - U.S. scout survivors			
HMMWV	---	YES	YES	YES
Light	---	---	YES	NO
Moderate	---	---	---	YES
	MOE 4 - Avg range of U.S. scouts detected by Iraqi forces			
HMMWV	---	NO	NO	NO
Light	---	---	NO	NO
Moderate	---	---	---	NO
	MOE 5 - Time difference of first detections			
HMMWV	---	NO	NO	YES
Light	---	---	NO	NO
Moderate	---	---	---	NO
	MOE 6 - # of kills by U.S. scouts			
HMMWV	---	NO	NO	YES
Light	---	---	NO	YES
Moderate	---	---	---	YES

Table 4. Tukey's Method for Fort Knox

2. Naval Postgraduate School simulation runs

The results from the simulation runs made by the Naval Postgraduate School operators are summarized in Table 5 on the following page.

	MOE 1 - Avg range of U.S. detections			
	HMMWV	Light	Moderate	Heavy
HMMWV	---	NO	NO	YES
Light	---	---	NO	NO
Moderate	---	---	---	NO
	MOE 2 - Total # detected by U.S. scouts			
HMMWV	---	YES	YES	YES
Light	---	---	NO	NO
Moderate	---	---	---	NO
	MOE 3 - U.S. scout survivors			
HMMWV	---	YES	YES	YES
Light	---	---	YES	NO
Moderate	---	---	---	NO
	MOE 4 - Avg range of U.S. scouts detected by Iraqi forces			
HMMWV	---	NO	NO	NO
Light	---	---	NO	YES
Moderate	---	---	---	NO
	MOE 5 - Time difference of first detections			
HMMWV	---	NO	YES	YES
Light	---	---	YES	YES
Moderate	---	---	---	NO
	MOE 6 - # of kills by U.S. scouts			
HMMWV	---	NO	YES	YES
Light	---	---	YES	YES
Moderate	---	---	---	YES

Table 5. Tukey's Method for NPS

C. HIERARCHICAL ADDITIVE WEIGHTING METHOD (HAWM)

1. Fort Knox simulation runs

Tukey's method enabled comparison between vehicles based on the individual MOEs. The hierarchical additive weighting method (HAWM) was employed in order to provide a structured approach for organizing the problem data to determine the best vehicle. The first step in establishing the priorities of elements in this problem is to make pairwise comparisons of the elements against the MOEs. The pairwise comparisons are best displayed in a matrix. The matrix is a tool that offers a framework for making all possible comparisons, and analyzing the sensitivity of overall priorities to changes in judgment. The matrix approach reflects the dual aspects of priorities: dominating and dominated.

To begin the pairwise comparison process, start at the top of the hierarchy to select the measure of effectiveness that will be used for making the first comparison. Then from the level immediately below, take the vehicle alternatives to be compared. To fill in the matrix of pairwise comparisons, numbers are used to represent the relative importance of one alternative over another with respect to the measure of effectiveness. Values range from one (equal importance) through nine (extreme importance). Table 6, on the next page, summarizes the pairwise comparison scale. [Ref 11] The numerically translated judgments are approximations, and are entirely based on the experience and real-life application of the system by the one assigning the relative importance.

When comparing one element in a matrix with itself, the comparison must give unity. Always compare the first element of a pair (the element in the left-hand column of the matrix) with the second (the element in the row on top) and estimate the numerical value from the scale in Table 6. The reciprocal value is then used for the comparison of the second element with the first.

After filling in the matrix, judgments must be synthesized to get an overall estimate of the relative priorities of the vehicles in relation to the measure of effectiveness. To do

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the property
3	Moderate importance of one over another	Experience and judgment slightly favor one element over another
5	Essential or strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	An element is strongly favored and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

Table 6. The Pairwise Comparison Scale

so, add the values in each column and then divide each entry in each column by the total of that column to obtain the normalized matrix. This permits meaningful comparisons among the vehicles. Finally , the rows are averaged by adding the values in each row of the normalized matrix and dividing the rows by the number of entries.

If Tukey's method discerned a significant difference between vehicles, then a value of five (strong importance) was assigned to the vehicle comparison matrix, otherwise a value of one was assigned. Initially, the value of five was chosen because it lies in the middle of the range of values. Appendix E contains the pairwise comparison matrix for all the measures of effectiveness. Table 7 illustrates the pairwise comparison matrix for the first measure of effectiveness for the Fort Knox operators.

	HMMWV	Light	Moderate	Heavy
HMMWV	1	1	1/5	1/5
Light	1	1	1	1
Moderate	5	1	1	1
Heavy	5	1	1	1

Table 7. Example of Pairwise Comparison Using MOE 1

Table 8 shows the normalized matrix for the first measure of effectiveness for obtaining the priority values.

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	0.083	0.25	0.0625	0.0625	0.1145
Light	0.083	0.25	0.3125	0.3125	0.2395
Moderate	0.417	0.25	0.3125	0.3125	0.3230
Heavy	0.417	0.25	0.3125	0.3125	0.3230

Table 8. Normalized Matrix for MOE 1

The next step was to determine the relative importance among all the measures of effectiveness. Using military judgment, the MOEs fell into two groups, MOEs 1 through 3 and MOEs 4 through 6, with MOEs in each group having equal importance. The first group contained the slightly more critical criteria and was assigned a value of three: Weak importance when compared to the other group of MOEs (Table 9).

	1	2	3	4	5	6	Priority
1	1	1	1	3	3	3	0.250
2	1	1	1	3	3	3	0.250
3	1	1	1	3	3	3	0.250
4	1/3	1/3	1/3	1	1	1	0.083
5	1/3	1/3	1/3	1	1	1	0.083
6	1/3	1/3	1/3	1	1	1	0.083

Table 9. Normalized MOE Matrix

The final step is the combining of the priority values of the vehicles within each MOE and the priority values among the MOEs to determine the best alternative. The final priority score is obtained by multiplying MOE priority by the priority of the vehicle with respect to the MOE and summing across the rows. The highest score represents the preferred vehicle. Table 10, on the next page, displays the final results.

For the Fort Knox operators the heavy variant was ranked the best alternative followed, in order, by the light version, the moderate, and finally the HMMWV.

Additional analysis was conducted on the sensitivity of the values assigned in the pairwise comparison matrix. Use of the values of three, seven, and nine did not change the conclusion of choosing the heavy variant over the other alternatives. Also, because

	1	2	3	4	5	6	Priority
Priority	0.25	0.25	0.25	0.083	0.083	0.083	
HMMWV	0.1145	0.0625	0.0616	0.25	0.1719	0.125	0.106
Light	0.2395	0.3125	0.3981	0.25	0.2343	0.125	0.288
Moderate	0.323	0.3125	0.1418	0.25	0.2343	0.125	0.245
Heavy	0.323	0.3125	0.3981	0.25	0.3594	0.625	0.361

Table 10. Combined Priorities

of the dominance in firepower for the heavy variant, in the measure of effectiveness for the number of kills, the rankings were redone with this measure deleted. Once again, the heavy variant was the preferred alternative Changing the values of the relative importance between the two groups of the measures of effectiveness did not affect choosing the heavy variant as the alternative for the scout platoon vehicle.

2. Naval Postgraduate School simulation runs

Table 11 displays the priority matrix from the data produced by the NPS operators.

	1	2	3	4	5	6	Priority
Priority	0.25	0.25	0.25	0.083	0.083	0.083	
HMMWV	0.172	0.0625	0.059	0.234	0.083	0.081	0.106
Light	0.234	0.3125	0.434	0.172	0.082	0.081	0.274
Moderate	0.234	0.3125	0.212	0.234	0.417	0.279	0.267
Heavy	0.359	0.3125	0.295	0.360	0.417	0.560	0.353

Table 11. Combined Priorities

For the NPS operators the heavy variant was ranked the best alternative followed, in order, by the light version, the moderate, and finally the HMMWV As in the Fort Knox case, adjusting the values in the pairwise comparison matrix did not change the final conclusion of choosing the heavy variant The only change noticed was when the groups of MOEs were weighted equally In this case, the moderate version was ranked second with the light version ranking third and the HMMWV last. In all cases, the heavy variant is the preferred alternative as the vehicle for the scout platoon.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

Using Scheffé's method with the Fort Knox operators, the FSV variants, taken as a group, outperformed the HMMWV in the following MOEs: average range of U.S. detections, total number detected by U.S. scouts, the number of U.S. scout survivors, and the number of kills by U.S. scouts. There were no discernible differences in the following two MOEs: the average range of detection by the Iraqis of the U.S. scouts, and the time difference of first detections. The analysis determined that the FSV variants were better in the number of kills by the U.S. scouts, but this was entirely due to the amount of kills registered by the heavy variant. Because of this fact one cannot conclude that all the variants are better than the HMMWV platoon in this measure. Considering the analysis of the other five measures, the FSV variants outperformed the HMMWV and are a better vehicle suited for the zone reconnaissance mission.

Using Scheffé's method with the NPS operators, the FSV variants outperformed the HMMWV in the following MOEs: the total number detected by the U.S. scouts, the number of U.S. scout survivors, the time difference of first detections, and the number of kills by the U.S. scouts. There were no discernible differences in the following two MOEs: the average range of detection by the U.S. scouts, and the average range of detection by the Iraqi's of the U.S. scouts. The FSV variants did outperform the HMMWV in the number of kills by the U.S. scouts, but this was due to the amount of kills registered by the heavy variant. Based on the analysis, though, of all the measures, the FSV variant did outperform the HMMWV in performing the tasks necessary to perform a zone reconnaissance.

Based on Tukey's method, in conjunction with HAWM, the heavy variant appears to be the best alternative for the scout platoon configuration when it performs a zone reconnaissance as part of a battalion movement-to-contact. When the MOEs (the average range of U.S. detections, the total number detected by U.S. scouts, and the number of U.S. scout survivors) were weighted greater than the MOEs (the average range of detection by the Iraqi's of the U.S. scouts, the time difference of first detections, and the number of kills by the U.S. scouts), the rankings were, in order, the heavy variant, the light variant, the moderate variant, and the HMMWV. These rankings were consistent when computed with either the Fort Knox or NPS operators.

When the measures of effectiveness were weighted equally the heavy variant was the best alternative for both sets of operators. The rankings for the Fort Knox operators were the heavy variant, the light variant, the moderate variant, followed by the HMMWV. The rankings for the NPS operators were the heavy variant, the moderate variant, the light variant, followed by the HMMWV. Regardless of the operators the heavy variant was consistently the best alternative.

B. RECOMMENDATIONS

Given this mission of performing a zone reconnaissance as part of a battalion movement-to-contact, under these specific circumstances, the recommendation would be to configure the scout platoon with the heavy variant of the Future Scout Vehicle. The conclusion was reached by analyzing data produced by independent operators in two different locations: Fort Knox and the Naval Postgraduate School.

The differences within the measures of effectiveness could be based on the use of distinct operators in both locations. The operators based the simulation runs on their own experience and background for interpretation of current U.S. doctrine. One extension of this study would be to run the simulation with a group of operators that are alike in experience level in conducting a battalion level movement-to-contact and then compare the results.

In this study six measures of effectiveness, with varying degrees of importance, were used. The rankings of the importance of these measures were the views of the author in what is significant in conducting a zone reconnaissance. There exist numerous ways in assigning weights in the hierarchical additive weighted method. One could use the methods described within this study to assign different weights to the measures of effectiveness based on different scout platoon missions or objectives. Thus, these methods could be used to determine the best scout platoon alternative for each mission.

LIST OF REFERENCES

1. Doyle, Brigadier General D. K., "The Indispensable Scout," *Armor*, p. 10, September- October 1977.

2. Field Manual 17-98(Initial Draft), *Scout Platoon*, pp. 1-4, Fort Knox, KY, 1993.

3. U.S. Army Armor Center and School, *White Paper - The Value of Reconnaissance*, p. 1, Fort Knox, KY, 1993.

4. Department of the Army, *Army Modernization Plan - Close Combat Heavy*, p. A-42, Office of the Assistant Deputy Chief of Staff for Operations and Plans, Force Development, p. A-14, Washington, DC, 1993.

5. Department of the Army, *Janus Version 3.0 Users Manual*, p. 2, Headquarters TRADOC Analysis Command, Fort Leavenworth, KS.

6. Sun Tzu, *The Art of War*, p. 98, Oxford University Press, 1963.

7. Department of the Army, *How They Fight - Desert Shield Order of Battle Handbook*, p. 49, U.S. Army Intelligence and Threat Analysis Center, 1990.

8. Department of the Army, *Future Scout Vehicle - Janus Analytical Plan*, pp. 16-21, U.S. Army Armor Center, Fort Knox, KY, 1993.

9. Neter, Wasserman, Kutner, *Applied Linear Statistical Models*, p. 529, Irwin, 1990.

10. Montgomery, Douglas C., *Design and Analysis of Experiments*, p. 96, John Wiley & Sons, Inc., 1991.

11. Saaty, Thomas L., *Decision Making for Leaders*, p. 78, RWS Publications, 1990.

APPENDIX A. MEASURES OF EFFECTIVENESS

Fort Knox Simulation Runs				
		FSV		
	HUMMV	Light	Moderate	Heavy
	5.575	5.386	5.996	6.929
	4.735	5.603	6.423	5.698
Average range of detection	5.402	5.738	6.228	6.762
	5.366	5.992	6.317	5.953
	5.802	6.068	6.408	5.763
	5.828	5.604	6.352	5.862
	HUMMV	Light	Moderate	Heavy
	38	100	67	77
	34	64	57	44
Total # detected by U.S. scouts	33	53	61	54
	54	68	85	87
	61	68	68	64
	31	62	65	81
	HUMMV	Light	Moderate	Heavy
	1	10	8	10
	1	6	2	6
U.S. Scout survivors	0	8	3	7
	0	5	4	6
	1	5	4	8
	0	8	4	6
	HUMMV	Light	Moderate	Heavy
	3.783	3.177	3.600	4.009
	3.789	3.369	2.827	3.382
Average range of U.S. scouts detected by IRAQ	4.012	3.206	3.216	2.244
	3.551	4.276	3.510	3.123
	3.847	4.134	4.161	2.535
	3.916	3.399	3.426	3.697

	HUMMV	Light	Moderate	Heavy
	7.18	7.75	5.39	18.48
	2.78	6.69	9.52	7.55
Time difference of first detections	4.71	4.82	9.05	7.13
	5.38	8.62	7.38	12.08
	10.55	9.18	9.98	16.16
	2.59	8.35	8.65	7.58
	HUMMV	Light	Moderate	Heavy
	0	0	0	18
	0	0	2	13
# of kills by scouts	0	0	2	19
	0	0	2	17
	0	0	1	19
	0	0	2	19

NPS Simulation Runs				
		FSV		
	HMMWV	Light	Moderate	Heavy
	6.702	6.262	7.3	7.03
	6.418	5.832	6.154	6.706
Average range of detection	6.083	6.877	6.665	7.283
	6.284	6.056	6.805	6.837
	6.494	6.456	6.553	6.837
	5.641	6.992	6.774	7.068
	HMMWV	Light	Moderate	Heavy
	22	39	71	71
	35	67	66	57
Total # detected by U.S. scouts	29	57	74	62
	21	63	84	55
	27	54	55	63
	16	59	65	57
	HMMWV	Light	Moderate	Heavy
	2	5	5	4
	1	6	4	5
U.S. Scout survivors	1	7	5	7
	3	8	6	5
	2	7	4	6
	3	7	4	4
	HMMWV	Light	Moderate	Heavy
	3.798	3.175	3.549	4.302
	3.228	2.805	2.616	4.123
Average range of U.S. scouts detected by IRAQ	3.466	3.297	3.987	4.074
	3.558	2.994	4.256	4.063
	3.679	3.545	3.855	4.216
	3.536	3.336	4.016	3.498

	HMMWV	Light	Moderate	Heavy
	1.21	5.75	12.44	11.34
	6.22	4.94	10.11	14.64
Time difference of first detections	6.74	5.15	9.08	17.48
	3.41	3.77	12.99	14.81
	5.07	5.97	6.75	7.31
	1.38	8.05	9.77	15.97
	HMMWV	Light	Moderate	Heavy
	0	0	10	23
	0	0	5	31
# of kills by scouts	0	0	6	31
	0	0	6	19
	0	0	8	25
	0	0	4	23

APPENDIX B. ANALYSIS OF VARIANCE

Fort Knox Simulation Runs						
MOE 1: Single Factor - Avg range of detections						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HUMMV	6	32.708	5.451	0.1606		
Light	6	34.391	5.732	0.0667		
Moderate	6	37.724	6.287	0.0253		
Heavy	6	36.967	6.161	0.2913		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.6854	3	0.8951	6.5839	0.0028	3.0984
Within Groups	2.7191	20	0.1360			
Total	5.4045	23				
MOE 2: Single Factor - # of detections						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HUMMV	6	251	41.833	157.3667		
Light	6	415	69.167	258.5667		
Moderate	6	403	67.167	92.9667		
Heavy	6	407	67.833	279.7667		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3106.6667	3	1035.5556	5.2522	0.0078	3.0984
Within Groups	3943.3333	20	197.1667			
Total	7050	23				

MOE 3: Single Factor - # of survivors						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HUMMV	6	3	0.500	0.3000		
Light	6	42	7.000	4.0000		
Moderate	6	25	4.167	4.1667		
Heavy	6	43	7.167	2.5667		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	175.7917	3	58.5972	21.2437	0.0000	3.0984
Within Groups	55.1667	20	2.7583			
Total	230.9583	23				

MOE 4: Single Factor - Average range of scouts being detected						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HUMMV	6	22.898	3.816	0.0243		
Light	6	21.561	3.594	0.2340		
Moderate	6	20.740	3.457	0.1950		
Heavy	6	18.990	3.165	0.4579		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.3360	3	0.4453	1.9552	0.1533	3.0984
Within Groups	4.5554	20	0.2278			
Total	5.8914	23				

MOE 5: Single Factor - Time difference of first detections						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HUMMV	6	33.190	5.532	8.9648		
Light	6	45.410	7.568	2.5345		
Moderate	6	49.970	8.328	2.8611		
Heavy	6	68.980	11.497	24.1676		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	110.3975	3	36.7992	3.8205	0.0259	3.0984
Within Groups	192.6398	20	9.6320			
Total	303.0373	23				

MOE 6: Single Factor - # of kills						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HUMMV	6	0	0.000	0		
Light	6	0	0.000	0		
Moderate	6	9	1.500	0.7		
Heavy	6	105	17.500	5.5		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1309.5	3	436.5	281.6129	0.0000	3.0984
Within Groups	31	20	1.55			
Total	1340.5	23				

NPS Simulation Runs						
MOE 1: Single Factor - Avg range of detections						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HMMWV	6	37.622	6.270	0.138		
Light	6	38.475	6.413	0.208		
Moderate	6	40.251	6.709	0.139		
Heavy	6	41.761	6.960	0.043		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.7084	3	0.5695	4.3104	0.0169	3.0984
Within Groups	2.6424	20	0.1321			
Total	4.3508	23				
MOE 2: Single Factor - # of detections						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HMMWV	6	150	25.000	45.200		
Light	6	339	56.500	94.300		
Moderate	6	415	69.167	94.967		
Heavy	6	365	60.833	34.567		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6713.4583	3	2237.8194	33.2720	0.0000	3.0984
Within Groups	1345.1667	20	67.2583			
Total	8058.6250	23				

MOE 3: Single Factor - # of survivors						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HMMWV	6	12	2.000	0.8000		
Light	6	40	6.667	1.0667		
Moderate	6	28	4.667	0.6667		
Heavy	6	31	5.167	1.3667		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	68.1250	3	22.7083	23.2906	0.0000	3.0984
Within Groups	19.5000	20	0.9750			
Total	87.6250	23				
MOE 4: Single Factor - Average range of scouts being detected						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HMMWV	6	21.265	3.544	0.0378		
Light	6	19.152	3.192	0.0691		
Moderate	6	22.279	3.713	0.3424		
Heavy	6	24.276	4.046	0.0803		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.2742	3	0.7581	5.7244	0.0054	3.0984
Within Groups	2.6485	20	0.1324			
Total	4.9227	23				

MOE 5: Single Factor - Time difference of first detections						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HMMWV	6	24.030	4.005	5.7155		
Light	6	33.630	5.605	2.0298		
Moderate	6	61.140	10.190	5.2302		
Heavy	6	81.550	13.592	13.5777		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	343.6482	3	114.5494	17.2559	0.0000	3.0984
Within Groups	132.7654	20	6.6383			
Total	476.4136	23				
MOE 6: Single Factor - # of kills						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HMMWV	6	0	0.000	0.0000		
Light	6	0	0.000	0.0000		
Moderate	6	39	6.500	4.7000		
Heavy	6	152	25.333	23.0667		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2584.1250	3	861.3750	124.0876	0.0000	3.0984
Within Groups	138.8333	20	6.9417			
Total	2722.9583	23				

APPENDIX C. SCHEFFÉ'S METHOD OF MULTIPLE COMPARISONS

A. FORT KNOX SIMULATION RUNS

1. Average range of detection by U.S. scouts

$$L = \frac{5.73 + 6.16 + 6.29}{3} - 5.45 = 0.61$$

$$S_{\hat{L}} = \sqrt{0.1359\left[\frac{\left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + (-1)^2}{6}\right]} = 0.1738$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\hat{L} = 0.61 \pm (3.0496)(0.1738) = 0.61 \pm 0.53$$

2. Total number detected by U.S. scouts

$$L = \frac{67.17 + 67.83 + 69.17}{3} - 41.83 = 26.23$$

$$S_{\hat{L}} = \sqrt{197.17\left[\frac{\left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + (-1)^2}{6}\right]} = 6.62$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\hat{L} = 26.23 \pm (3.0496)(6.62) = 26.23 \pm 20.19$$

3. U.S. scout survivors

$$L = \frac{4.17 + 7.00 + 7.17}{3} - 0.50 = 5.61$$

$$S_{\hat{B}} = \sqrt{2.758\left[\frac{\left(\frac{1}{3}\right)^2+\left(\frac{1}{3}\right)^2+\left(\frac{1}{3}\right)^2+(-1)^2}{6}\right]} = 0.783$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\vec{B} = 5.61 \pm (3.0496)(0.783) = 5.61 \pm 2.39$$

4. Average range of detection of U.S. scouts

$$L = 3.82 - \frac{3.17+3.46+3.59}{3} = 0.41$$

$$S_{\hat{B}} = \sqrt{0.2278\left[\frac{\left(\frac{1}{3}\right)^2+\left(\frac{1}{3}\right)^2+\left(\frac{1}{3}\right)^2+(-1)^2}{6}\right]} = 0.225$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\vec{B} = 0.41 \pm (3.0496)(0.225) = 0.41 \pm 0.69$$

5. Time difference of first detections

$$L = \frac{11.50+8.33+7.57}{3} - 5.53 = 3.60$$

$$S_{\hat{B}} = \sqrt{9.632\left[\frac{\left(\frac{1}{3}\right)^2+\left(\frac{1}{3}\right)^2+\left(\frac{1}{3}\right)^2+(-1)^2}{6}\right]} = 1.46$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\vec{B} = 3.60 \pm (3.0496)(1.46) = 3.60 \pm 4.46$$

6. Number of kills by U.S. scouts

$$L = \frac{0.00+1.50+17.5}{3} - 0.00 = 6.33$$

$$S_{\hat{P}} = \sqrt{1.55\left[\frac{\left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + (-1)^2}{6}\right]} = 0.59$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\hat{P} = 6.33 \pm (3.0496)(0.587) = 6.33 \pm 1.80$$

B. NPS SIMULATION RUNS

1. Average range of detection by U.S. scouts

$$\hat{L} = \frac{6.41 + 6.71 + 6.96}{3} - 6.27 = 0.42$$

$$S_{\hat{P}} = \sqrt{0.1321\left[\frac{\left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + (-1)^2}{6}\right]} = 0.171$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\hat{P} = 0.42 \pm (3.0496)(0.171) = 0.42 \pm 0.52$$

2. Total number detected by U.S. scouts

$$L = \frac{56.50 + 60.83 + 69.17}{3} - 25.00 = 37.17$$

$$S_{\hat{P}} = \sqrt{67.26\left[\frac{\left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + (-1)^2}{6}\right]} = 3.87$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\hat{P} = 37.17 \pm (3.0496)(3.87) = 37.17 \pm 11.79$$

3. U.S. scout survivors

$$L = \frac{4.67 + 5.17 + 6.67}{3} - 2.00 = 3.50$$

$$S_{\bar{B}} = \sqrt{0.9750\left[\frac{\left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + (-1)^2}{6}\right]} = 0.465$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\bar{B} = 3.50 \pm (3.0496)(0.465) = 3.50 \pm 1.42$$

4. Average range of detections of U.S. scouts

$$L = \frac{4.05 + 3.71 + 3.19}{3} - 3.54 = 0.106$$

$$S_{\bar{B}} = \sqrt{0.1324\left[\frac{\left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + (-1)^2}{6}\right]} = 0.172$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\bar{B} = 0.11 \pm (3.0496)(0.172) = 0.11 \pm 0.53$$

5. Time difference of first detections

$$L = \frac{5.61 + 10.19 + 13.59}{3} - 4.01 = 5.79$$

$$S_{\bar{B}} = \sqrt{6.638\left[\frac{\left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + (-1)^2}{6}\right]} = 1.215$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\bar{B} = 5.79 \pm (3.0496)(1.215) = 5.79 \pm 3.71$$

6. Number of kills by U.S. scouts

$$L = \frac{0.00 + 6.50 + 25.33}{3} - 0.00 = 10.61$$

$$S_{\hat{L}} = \sqrt{6.942\left[\frac{\left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + (-1)^2}{6}\right]} = 1.242$$

$$K = \sqrt{3F[.95;3,20]} = \sqrt{3(3.10)} = 3.0496$$

$$\hat{L} = 10.61 \pm (3.0496)(1.242) = 10.61 \pm 3.79$$

APPENDIX D. TUKEY'S METHOD OF MULTIPLE COMPARISONS

A. FORT KNOX SIMULATIONS

1. Average range of detections by U.S. scouts

$$q_{.05}(4,20) = 3.96$$

$$S_{\bar{Y}_i} = \sqrt{\frac{0.1359}{6}} = 0.1505$$

$$T_{.05} = (3.96)(0.1505) = 0.60$$

	HMMWV	Light	Heavy	Moderate
Avg range of detection	5.45	5.73	6.16	6.29

where the lines represent the difference of the means that are less than the $T_{.05}$ value. These lines represent the results that are not significantly different from each other.

2. Total number of detections by U.S. scouts

$$S_{\bar{Y}_i} = \sqrt{\frac{197.17}{6}} = 5.73$$

$$T_{.05} = (3.96)(5.73) = 22.70$$

	HMMWV	Mod	Heavy	Light
# of detections	41.833	67.167	67.833	69.167

3. U.S. scout survivors

$$S_{\bar{Y}_i} = \sqrt{\frac{2.76}{6}} = 0.68$$

$$T_{.05} = (3.96)(0.68) = 2.69$$

	HMMWV	Mod	Light	Heavy
# of survivors	0.500	4.167	7.000	7.167

4. Average range of U.S. scouts being detected by Iraqi forces

$$S_{\bar{Y}_i} = \sqrt{\frac{0.23}{6}} = 0.20$$

$$T_{.05} = (3.96)(0.20) = 0.77$$

	Heavy	Mod	Light	HMMWV
Avg range of scouts being detected	3.165	3.457	3.594	3.816

5. Time difference of first detections

$$S_{\bar{Y}_i} = \sqrt{\frac{9.63}{6}} = 1.27$$

$$T_{.05} = (3.96)(1.27) = 5.02$$

	HMMWV	Light	Mod	Heavy
Time difference of first detections	5.532	7.568	8.328	11.497

6. Number of kills by U.S. scouts

$$S_{\bar{Y}_i} = \sqrt{\frac{1.55}{6}} = 0.51$$

$$T_{.05} = (3.96)(0.51) = 2.01$$

	HMMWV	Light	Mod	Heavy
# of kills	0.000	0.000	1.500	17.500

B. NAVAL POSTGRADUATE SCHOOL SIMULATIONS

1. Average range of detections by U.S. scouts

$$S_{\bar{Y}_i} = \sqrt{\frac{0.13\_1}{6}} = 0.15$$

$$T_{.05} = (3.96)(0.15) = 0.59$$

	HMMWV	Light	Mod	Heavy
Avg. range of detection	6.270	6.413	6.709	6.960

2. Total number of detections by U.S. scouts

$$S_{\bar{Y}_i} = \sqrt{\frac{67.26}{6}} = 3.35$$

$$T_{.05} = (3.96)(3.35) = 13.26$$

	HMMWV	Light	Heavy	Mod
# of detections	25.000	56.500	60.833	69.167

3. U.S. scout survivors

$$S_{\bar{Y}} = \sqrt{\frac{0.975}{6}} = 0.40$$

$$T_{.05} = (3.96)(0.40) = 1.60$$

	HMMWV	Mod	Heavy	Light
# of survivors	2.000	4.667	5.167	6 667

4. Average range of U.S. scouts being detected by Iraqi forces

$$S_{\bar{Y}_i} = \sqrt{\frac{0\,1324}{6}} = 0.15$$

$$T_{05} = (3\ 96)(0\ 15) = 0.59$$

	Light	HMMWV	Mod	Heavy
Avg range of scouts being detected	3.192	3.544	3.713	4.046

5. Time difference of first detections

$$S_{\bar{Y}_i} = \sqrt{\frac{6.64}{6}} = 1\,05$$

$$T_{05} = (3\ 96)(1\ 05) = 4\ 17$$

	HMMWV	Light	Mod	Heavy
Time difference of first detections	4 005	5 605	10 190	13 592

6. Number of kills by U.S. scouts

$$S_{\bar{Y}} = \sqrt{\frac{6.94}{6}} = 1.08$$

$$T_{.05} = (3.96)(1.08) = 4.26$$

	HMMWV	Light	Mod	Heavy
# of kills	0.000	0.000	6.500	25.333

APPENDIX E. HIERARCHICAL ADDITIVE WEIGHTING METHOD

A. FORT KNOX SIMULATION RUNS

1. Average range of U.S. detections

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1	1/5	1/5	0.1145
Light	1	1	1	1	0.2395
Moderate	5	1	1	1	0.3230
Heavy	5	1	1	1	0.3230

2. Total number detected by U.S. scouts

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1/5	1/5	1/5	0.0625
Light	5	1	1	1	0.3125
Moderate	5	1	1	1	0.3125
Heavy	5	1	1	1	0.3125

3. U.S. scout survivors

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1/5	1/5	1/5	0.0616
Light	5	1	5	1	0.3981
Moderate	5	1/5	1	1/5	0.1418
Heavy	5	1	5	1	0.3981

4. Average range of U.S. scouts detected by Iraqi forces

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1	1	1	0.25
Light	1	1	1	1	0.25
Moderate	1	1	1	1	0.25
Heavy	1	1	1	1	0.25

5. Time difference of first detection

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1	1	1/5	0.1719
Light	1	1	1	1	0.2343
Moderate	1	1	1	1	0.2343
Heavy	5	1	1	1	0.3594

6. Number of kills by U.S. scouts

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1	1	1/5	0.125
Light	1	1	1	1/5	0.125
Moderate	1	1	1	1/5	0.125
Heavy	5	5	5	1	0.625

B. NPS SIMULATION RUNS

1. Average range of U.S. detections

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1	1	1/5	0.172
Light	1	1	1	1	0.234
Moderate	1	1	1	1	0.234
Heavy	5	1	1	1	0.359

2. Total number detected by U.S. scouts

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1/5	1/5	1/5	0.0625
Light	5	1	1	1	0.3125
Moderate	5	1	1	1	0.3125
Heavy	5	1	1	1	0.3125

3. **U.S. scout survivors**

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1/5	1/5	1/5	0.059
Light	5	1	5	1	0.434
Moderate	5	1/5	1	1	0.212
Heavy	5	1	1	1	0.295

4. **Average range of U.S. scouts detected by Iraqi forces**

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1	1	1	0.234
Light	1	1	1	1/5	0.172
Moderate	1	1	1	1	0.234
Heavy	1	5	1	1	0.360

5. **Time difference of first detections**

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1	1/5	1/5	0.083
Light	1	1	1/5	1/5	0.083
Moderate	5	5	1	1	0.417
Heavy	5	5	1	1	0.417

6. **Number of kills by U.S. scouts**

	HMMWV	Light	Moderate	Heavy	Priority
HMMWV	1	1	1/5	1/5	0.0805
Light	1	1	1/5	1/5	0.0805
Moderate	5	5	1	1/5	0.279
Heavy	5	5	5	1	0.560

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center — 2
   Cameron Station
   Alexandria, VA 22304-6154

2. Library, Code 52 — 2
   Naval Postgraduate School
   Monterey, CA 93943-5002

3. Deputy Undersecretary of the Army — 1
   for Operations Research
   Room 2E261, The Pentagon
   Washington, DC 20310

4. Director, U.S. Army Concepts Analysis Agency — 1
   ATTN: Mr. E. B. Vandiver III
   8120 Woodmont Avenue
   Bethesda, MD 20814

5. Commander — 1
   U.S. Army TRADOC Analysis Command
   ATTN: ATRC (Mr. Bauman)
   Fort Leavenworth, KS 66027-5200

6. Commander and Director — 1
   U.S. Army TRADOC Analysis Command
   TRAC-Monterey
   Monterey, CA 93943

7. Director — 1
   U.S. Army TRADOC Analysis Command-Fort Leavenworth
   ATTN: ATRC-FOQ (Technical Information Center)
   Fort Leavenworth, KS 66027-5200

8. Commander, USAARMC — 1
   Director, Combat Developments, Analysis Division
   ATTN: ATZK-CDM
   Fort Knox, KY 40121-5000

1. Professor Robert R. Read 2
Department of Operations Research
Naval Postgraduate School, Code OR/Re
Monterey, CA 93943-5121

2. Professor Samuel H. Parry 1
Department of Operations Research
Naval Postgraduate School, Code OR/Py
Monterey, CA 93943-5121

3. Captain John L. Salvetti 3
1401 Pelican Ct.
Murrells Inlet, SC 29576